BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 09027

SUBJECT: Satellite Placement and Retrieval by Use of a Space Shuttle - Case 105-4

DATE: September 11, 1970

FROM: H. B. Bosch

ABSTRACT

This memorandum extends and amplifies previously reported analyses of space shuttle performance capability in support of unmanned payloads. The direct launch of satellites by a shuttle is discussed, as well as launch by a shuttle-Agena or shuttle-Centaur combination via an intermediate orbit which is coplanar with the final orbit. The following additional cases are discussed: (1) satellite placement from the vicinity of a space station; (2) the capabilities of a reusable space tug in association with a shuttle; and (3) satellite retrieval, either directly by a shuttle or with the aid of an auxiliary stage.

It is shown that all earth orbiting satellites, except geosynchronous ones, are directly retrievable by a shuttle which has a nominal round trip payload capability of 50,000 pounds to and from a space station orbit at 55°/270 n.m. A shuttle with only a 25,000 pound capability for this same nominal round trip would require an Agena for retrieval of satellites in high inclination, sun-synchronous orbits. However it would still be able to retrieve satellites directly from low inclination orbits. Retrieval of communication satellites from geosynchronous orbit requires two staged tugs -- and hence at least two shuttle launches.

(NASA-CR-113607) SATELLITE PLACEMENT AND RETRIEVAL BY USE OF A SPACE SHUTTLE (Bellcomm, Inc.) 29 p

N79-71664

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FF No. 602

(X- 11360)
(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

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MEMORANDUM FOR FILE

I. INTRODUCTION

The existence of a completely reusable earth-to-orbit shuttle in the late 70's could have a potentially significant effect on an unmanned space program. The shuttle (with or without a third stage) may provide economical launch of satellites and planetary probes. Further, by virtue of the shuttle's ability to operate in low earth orbits, it may be used for visiting or retrieving satellites. The usefulness and desirability of such a feature of a future space transportation system has been discussed before (see, for example, References 1 and 2). This memorandum is intended to amplify the brief performance summary contained in Reference 2.

The performance capability of a shuttle, as well as the shuttle used in association with an Agena or Centaur stage, was previously analyzed in Reference 3 with regard to placement of unmanned satellites. The data reported in this memorandum extend the studies presented in Reference 3 to three additional mission modes as follows: (1) use of a space tug as an auxiliary stage with a space shuttle; (2) satellite launch from the vicinity of a space station; and (3) retrieval of satellites from orbit. These capabilities are then superposed on the performance requirements for some typical missions which were selected from an OSSA mission model for the 70's (Reference 4).

II. VEHICLE DEFINITIONS AND PERFORMANCE CAPABILITIES

The characteristics of an earth-to-orbit shuttle are described in Reference 3 and summarized below in Table 1. These characteristics were assumed to represent typical shuttle performance and were based on the major contractor studies. For the purposes of this study, the shuttle is a fully reusable booster and orbiter which is capable of carrying a 25,000 pound payload to and from a space station orbit 270 nm high at 55° inclination. Reflecting more advanced technology resulting in a lighter orbiter structure, a modified version is assumed capable of delivering a 50,000 pound payload to the same space station orbit and returning it to earth. For the sake of brevity in this memorandum, these two conceptual vehicles will be referred to as a 25K shuttle and a 50K shuttle, respectively.

TABLE I. ASSUMED SHUTTLE CHARACTERISTICS

	BOOSTER	ORBITER	COMBINED
Gross Weight	2,789,000 lbs	711,000*	3,500,000
Propellant	2,287,000 lbs	493,000	2,780,000
Burnout Weight	502,000 lbs	218,000*	---
Payload	---	25,000 or 50,000	---
I_{sp}	425 sec	460	---
ΔV to 55°/270 nm	14,500 fps	17,500	32,000
Deorbit ΔV	---	400 - 500 fps	---

*Including 25,000 or 50,000 pound payload

The Space Tug considered here is essentially a reusable propulsion stage for use on interorbital missions, and having an overall weight of 50,000 pounds.

The dry stage weight (W_s), maximum propellant capacity ($W_{p,max}$), and specific impulse (I_{sp}) assumed for the Agena, Centaur and space tug are listed in Table 2.

TABLE 2. ASSUMED UPPER STAGE CHARACTERISTICS

	W_s (pounds)	$W_{p,max}$ (pounds)	I_{sp} (seconds)
Agena	1,400	13,400	293
Centaur	4,100	29,900	442
Space Tug	7,500	42,500	460

It should be recognized that Agena and Centaur characteristics in fact vary from mission to mission. Hence the numbers shown in Table 2 (from Reference 5) are taken as typical of "Agena-class" and Centaur-class" stages, rather than representing specific vehicles. It must also be noted that the space tug is currently undergoing definition studies and that the corresponding values shown in Table 2 are those which were nominally assumed in the Integrated Program Plan (Reference 6). Therefore some of the conclusions of this study may be affected quantitatively by the variability of stage characteristics, although it is believed that the conclusions will remain qualitatively valid.

With these qualifications in mind, Figure 1 shows the payloads which these three stages can deliver as a function of characteristic velocity increment from some (arbitrary) initial orbit. Space tug performance is shown for both the recoverable and the expendable operating modes, while Agena and Centaur performance is for expendable modes. For payloads less than 3000 pounds an Agena has greater range (ΔV capability) than the space tug; and for all payloads a Centaur performs better. This is because the space tug is intended to be recoverable. But even if the tug is expendable it does not exceed a Centaur's performance significantly and, furthermore, has less maximum range than a Centaur for payloads less than 2400 pounds.

III. SATELLITE PLACEMENT

A. Launch Modes

The shuttle is assumed to ascend from KSC* to a 45nm/100 nm orbit and then transfer to a circular orbit, into

*Launch azimuth is assumed to be unconstrained. Thus the shuttle can inject into any inclination greater than 28.5°.

which it places a satellite with a required stage. The stage then delivers the satellite from this reference orbit into its final orbit.

Two types of reference orbit (i.e., initial orbit before satellite launch) are considered here. The first type is a 100 nm circular orbit, coplanar with the satellite's final orbit. However, since the shuttle is assumed to make a direct ascent (i.e., no dogleg or plane change), the lowest possible inclination for a reference orbit is 28.5° (due east launch from KSC). Therefore, the reference orbit for equatorial satellites (such as geostationary) is not equatorial but at 28.5°/100 nm.

The second type of reference orbit takes into consideration the possibility that the shuttle's primary mission might be to make scheduled flights to and from the space station at 55°/270 nm. Thus we also consider the mode where a stage and a satellite are delivered to the space station orbit, whence the stage then places the satellite into its final orbit.

The shuttle may not be able to deliver a fully fueled stage with its payload to the desired initial orbit. The payload limitations for the shuttle depend on the altitude and inclination of this orbit as shown on Figures 2 and 3 (see Reference 3). Thus, in order to keep the total weight within the bounds of the shuttle's payload capability, the payload deliverable to a given orbit may be increased by loading the stage with just enough fuel to provide the ΔV required for the mission. Figures 4, 5 and 6 show the total weight (W_t = dry stage + payload + fuel) of an offloaded stage as a function of payload (W_L) and velocity increment (ΔV) for an Agena, Centaur and space tug, respectively.

The capability of a particular shuttle-stage combination to launch a given satellite can be ascertained by using Figure 2 or 3 with Figures 4, 5 or 6, if the weight of the satellite is known as well as the characteristic velocity requirement from a given reference orbit.

Many other reference orbits could be considered. The choice of a 100 nm circular orbit is arbitrary. In fact the reference orbit might be optimized for each specific mission. By having the shuttle deliver the stage and satellite "closer" to the final orbit, the deliverable payload may be increased up to a point. If the shuttle is required to provide too much velocity, however, its payload capacity may be reduced to the extent that the stage has to be off-loaded and the net payload deliverable to the final orbit will again decrease. Figure 7 shows two examples of this for a 25K shuttle with an Agena stage. For placing a satellite into a sun-synchronous orbit (100°/800nm) with this combination, the choice of a 100°/100nm reference orbit appears to be good. For launching to a geostationary orbit (0°/19,300nm), however, the maximum deliverable payload can be increased from 2400 to 2900 pounds if the shuttle delivers the Agena and satellite to a circular orbit at 30°/540 nm instead of one at 30°/100 nm. Similar optimum reference orbits could be determined for other missions and for other shuttle-stage combinations. This example only points out such a tradeoff. A complete optimization is beyond the scope of this memorandum.

B. Satellite Placement from Coplanar Circular Orbit

The launch mode considered here is one in which the shuttle places the stage and satellite into a 100 nm circular orbit coplanar with the final orbit. The stage then delivers the satellite to its final orbit from this reference orbit.

The satellites shown on Figure 8c were selected from the mission model in Reference 4 as those whose cost was estimated at $25 M or more. These cost estimates were based on information contained in the planning panel position papers of the 1969 Planning Steering Group. The weights and orbital parameters were taken from the above mission model and are listed in Table 3. The ΔV requirements shown on Figure 8c correspond to a Hohman transfer from a 100 nm circular coplanar* reference orbit.

Figure 8b shows the performance capability of the three stages when they are delivered to a 100 nm circular orbit by a 25K shuttle. The branches and breaks in the performance curves are due to the shuttle's performance limits, as was pointed out in the previous section. For example, a 25K shuttle can deliver approximately 20,000 pounds to an orbit at 100°/100nm (see Figure 2). Since a fully fueled Agena weighs almost 15,000 pounds (see Table 2) this allows for a payload of 5000 pounds. For a heavier payload the Agena propellant must be offloaded by a corresponding amount so as to maintain a total weight of 20,000 pounds. This reduces the performance capability as shown by the branch on the Agena curve at a 5000 pound payload. Similar points occur on other curves at different payload weights. Figure 8a contains the same information relative to a 50K shuttle.

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*The reference orbit for equatorial satellites is 28.5°/100 nm since the shuttle cannot reach a lower inclination via direct ascent from KSC.

TABLE 3. SATELLITES USED FOR THIS STUDY (BASED ON REFERENCE 4)

SATELLITE (PROJECT) DESIGNATION	WEIGHT	ORBIT	V_c*	DESCRIPTIVE NAME
ASTRONOMY				
HEAO	23,000 lbs	55°/270 nm	690 fps	High Energy Astronomical Observatory
ATM	21,700	55°/270	690	Apollo Telescope Mount
Tel Tech	20,000	55°/270	690	80" Mirror Telescope Technology
LST	14,000	55°/270	690	Large Space Telescope
OAO	6,000	35°/400 (55°/270)	1,020 (690)	Orbiting Astronomical Observatory
OSO	700	55°/270	690	Orbiting Solar Observatory
EARTH OBSERVATION				
ERTS-C,D	1,500	100°/500	1,330	Earth Resources Technology Satellite
ERTS-E,F	2,000	100°/500	1,330	Earth Resources Technology Satellite
Polar GARP	1,500	100°/600	1,630	Global Atmospheric Research Program
Nimbus	1,500	100°/600	1,630	
COMMUNICATION				
Laser Comm	4,000	28.5°/19,300	12,920	Laser Communication Technology
ATS-F,G	3,870	0°/19,300	14,070	Applications Technology Satellite
ATS-H,J	2,200	0°/19,300	14,070	Applications Technology Satellite
DRSS	1,610	0°/19,300	14,070	Data Relay Satellite System
SST	1,610	0°/19,300	14,070	Satellite to Satellite Tracking
S-Band TV	1,500	0°/19,300	14,070	S-Band TV Broadcasting
Nav T/C	750	28.5°/19,300	12,920	Navigation & Traffic Control
PLANETARY				
Viking	9,700	---	14,000	'75 & '77 Mars Orbiter/Lander
Jupiter Sw'by	1,500	---	25,400	'77 Jup.-Sat.-Pluto & '79 Jup.-Uran.-Nept.

*V_c = characteristic velocity required at 100 nm

Overlaying Figure 8b onto 8c reveals those satellites which can be placed into orbit by using a 25K shuttle. Note that a 25K shuttle can place all astronomy satellites into low inclination orbit without the aid of an auxiliary stage. The sun-synchronous meteorology and earth resources satellites would require a tug or an Agena. The Agena is also capable of placing some communication type satellites into geosynchronous orbit. Using a Centaur then includes the remaining earth orbital missions as well as the important Viking missions and the Jupiter swingbys to Uranus-Neptune ('77) and to Saturn-Pluto ('79).

Overlaying Figure 8a shows the effects of using a 50K shuttle. The most significant difference is that a 50K shuttle can deliver all the astronomy and earth observation satellites directly. Otherwise, the payload range of the stages is extended somewhat but this does not introduce any satellites not covered by a 25K shuttle.

C. Satellite Placement from Space Station Orbit

Figure 9c shows the weights of the same satellites as were on Figure 8c, now plotted versus the characteristic velocity increment required for placement from a space station orbit at 55°/270 nm.

A reasonable assumption to make is that the astronomy facilities will be operating in the same orbit as the space station. Considering that in-orbit phasing propulsion requirements can be kept to a few hundred feet per second (see Reference 7), these satellites are shown near $\Delta V = 0$.

Some satellites* are shown with varying characteristic velocity requirement relative to the space station orbit, as indicated by the arrows. This is because differential nodal regression rates cause the plane change angle to vary - minimum when the ascending nodes are aligned and maximum when they are 180° apart (see Reference 8). Usually the time of launch can be chosen freely and the minimum ΔV shown applies. But if the time of launch (or the orientation of the orbit plane, as in the case of sun-synchronous satellites) is to be determined from other criteria then higher ΔVs may be required (e.g., up to 49,000 fps for sun-synchronous orbits). This is not to say that such extreme ΔVs will ever be called for, but to call attention to the variability of ΔV requirements.

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*Laser Communication, DRSS, ERTS, Nimbus, Polar GARP.

Overlaying Figure 9b onto 9c again reveals the capabilities of a 25K shuttle. The shuttle, operating to the space station, can place the astronomy satellites into nearby orbits. The Agena is seen to be capable of launching the DRSS, Nav T/C, and possibly the S-Band TV satellites. The Centaur, however, can launch all satellites shown.

Overlaying Figure 9a indicates that a 50K shuttle could maneuver the astronomy satellites with higher ΔV's, but that it does not appreciably improve the capabilities of the Agena. The improvement in the Centaur is essentially that there is a wider choice of orbits for the Laser Communication, DRSS, ERTS, Nimbus and Polar GARP satellites.

The characteristic velocity requirements for planetary launches from a space station orbit are not shown on Figure 9c, for the following reasons: The right ascension and declination of the departure asymptote (or V_∞ vector) are determined by the date of launch. But the launch dates for most planetary missions have not yet been fixed. Furthermore, in order to avoid out-of-plane escape burns, the departure trajectory should lie in a plane which contains this asymptote. This, in turn, constrains the inclination and ascending node of the orbit to satisfy a certain relationship. Therefore, not only is there a spectrum of departure trajectories to be chosen from, but also the geometric relationship between the departure trajectory and the space station orbit varies with time. However, in the event that the space station is in a favorable relationship to the departure trajectory so that plane change and phasing maneuvers are not required, then the minimum velocity (approximately as shown on Figure 8c) would apply. In this case a 50K shuttle with a Centaur might still be sufficient to launch these planetary missions.

IV. SATELLITE RETRIEVAL

The retrieval of satellites which are already in orbit is another type of mission which is conceivable for a shuttle to perform with the aid of a propulsion stage. For example, the shuttle might deliver an Agena, a Cenatur or a space tug to a 100 nm circular orbit. The stage would go to the satellite orbit and return with the satellite to the shuttle. Operationally this is more complex than satellite placement because retrieval involves in-orbit phasing, rendezvous, and docking maneuvers, both in the satellite orbit as well as in the shuttle orbit. However, some simplified retrieval missions could be considered, assuming phasing, rendezvous and docking maneuvers to require only minor ΔV's.

A theoretical tradeoff between delivered and returned payloads for the shuttle shows that the returned payload is essentially limited only by size and structural constraints (Figure 10). This is due to the low deorbiting ΔV (400-500 fps) relative to the ΔV required to reach orbit (e.g., 17,500 fps). Therefore, if a shuttle can reach a satellite, it can usually retrieve it. (See Figures 2 and 3 for the performance limits of the shuttles.)

The satellites shown on Figure 11c are the same as were shown on Figure 8c (except planetary missions). Overlaying Figure 11b* onto 11c reveals that a 25K shuttle with an Agena is sufficient to retrieve all astronomy, earth observation, and meteorology satellites. Overlaying Figure 11a indicates that, although a 50K shuttle with an upper stage can retrieve payloads from higher energy orbits, this does not introduce any satellites which are not already within capability of a 25K shuttle with an upper stage. These figures also show that satellites in (equatorial) geostationary orbit are not retrievable, at least not from a 100 nm reference orbit. Retrieval of this class of satellites would require either a higher reference orbit or two staged tugs delivered by two shuttle launches (Reference 10). Further elaboration of these modes is not within the scope of this memorandum.

Since a 25K shuttle can deliver all astronomy satellites directly, it can also retrieve them directly. Sun-synchronous orbits, however, are out of its reach. By comparison, a 50K shuttle can retrieve all low-to-medium altitude satellites directly.

V. SUMMARY

A 25K shuttle alone is capable of launching astronomy satellites but not earth observation or meteorology satellites. These satellites require the addition of an Agena. An Agena can also launch some of the communication satellites into geosynchronous orbit when it is delivered to a 28.5°/100 nm reference orbit. Use of a Centaur, instead of an Agena, launches all earth orbiting satellites as well as missions to Mars and the outer planets.

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*The dry weight of the Centaur has been increased by 700 pounds to account for the subsystems needed for a multiple-burn capability (Reference 9). The Agena and the tug already have this capability.

A 50K shuttle alone can launch all earth observation and meteorology satellites into sun-synchronous orbits. This is the major performance difference between a 25K and a 50K shuttle with respect to satellite launch and retrieval. Although a 50K shuttle does increase the performance of upper stages somewhat, this increase does not introduce any mission which is not already within the capability of a 25K shuttle with an upper stage.

A 25K shuttle alone is sufficient for retrieving all astronomy satellites, an Agena being required for retrieval of earth observation satellites. A 50K shuttle alone can retrieve all of these satellites. However, neither a 50K shuttle nor the addition of an upper stage is sufficient for retrieving (equatorial) geosynchronous satellites. Use of two staged tugs is indicated for these latter missions.

HB Bosch

1013-HBB-klm

H. B. Bosch

Attachments
References
Figures 1-11

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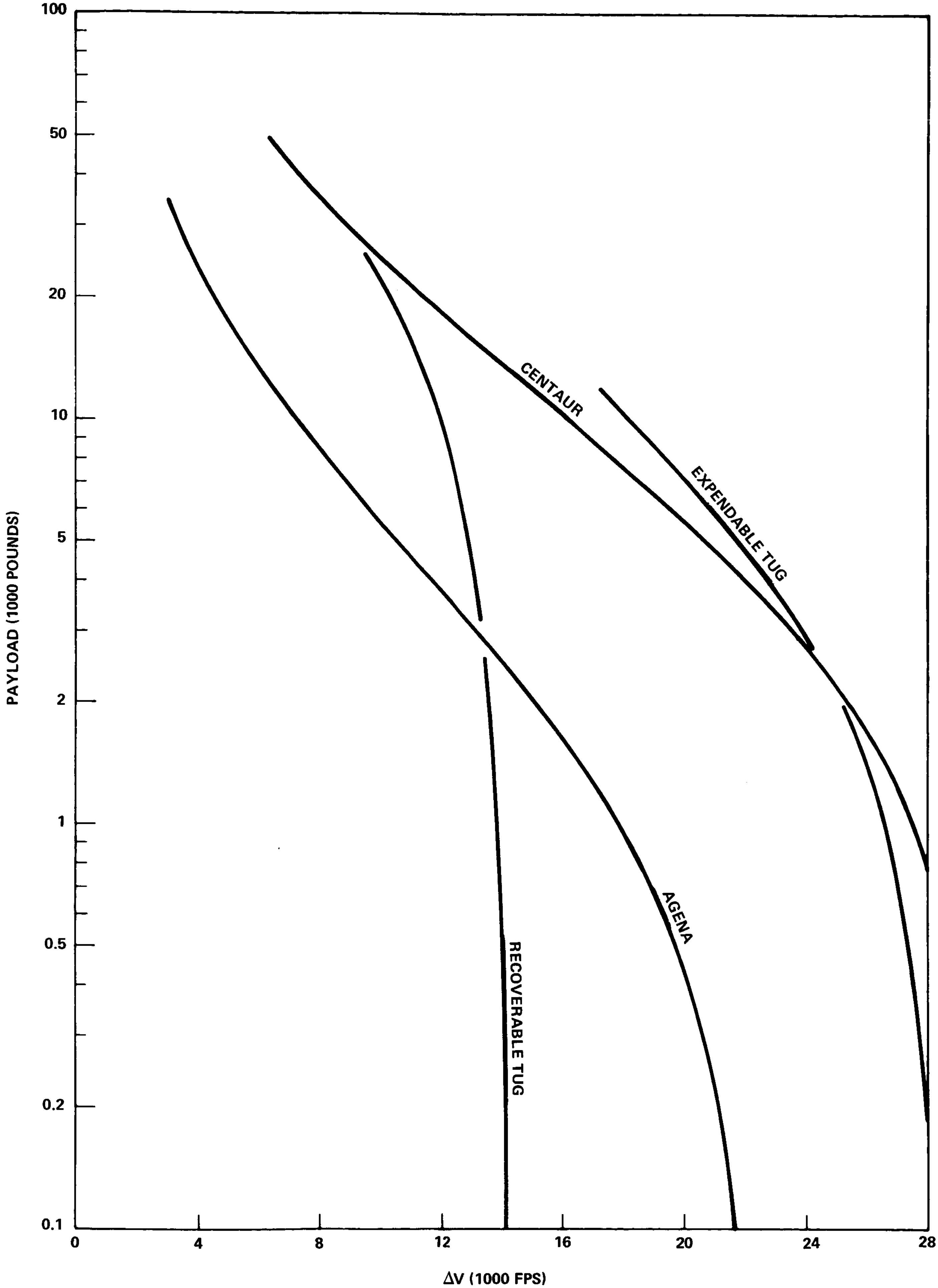

FIGURE 1 - PAYLOAD PLACEMENT CAPABILITIES OF THREE INSPACE PROPULSIVE STAGES

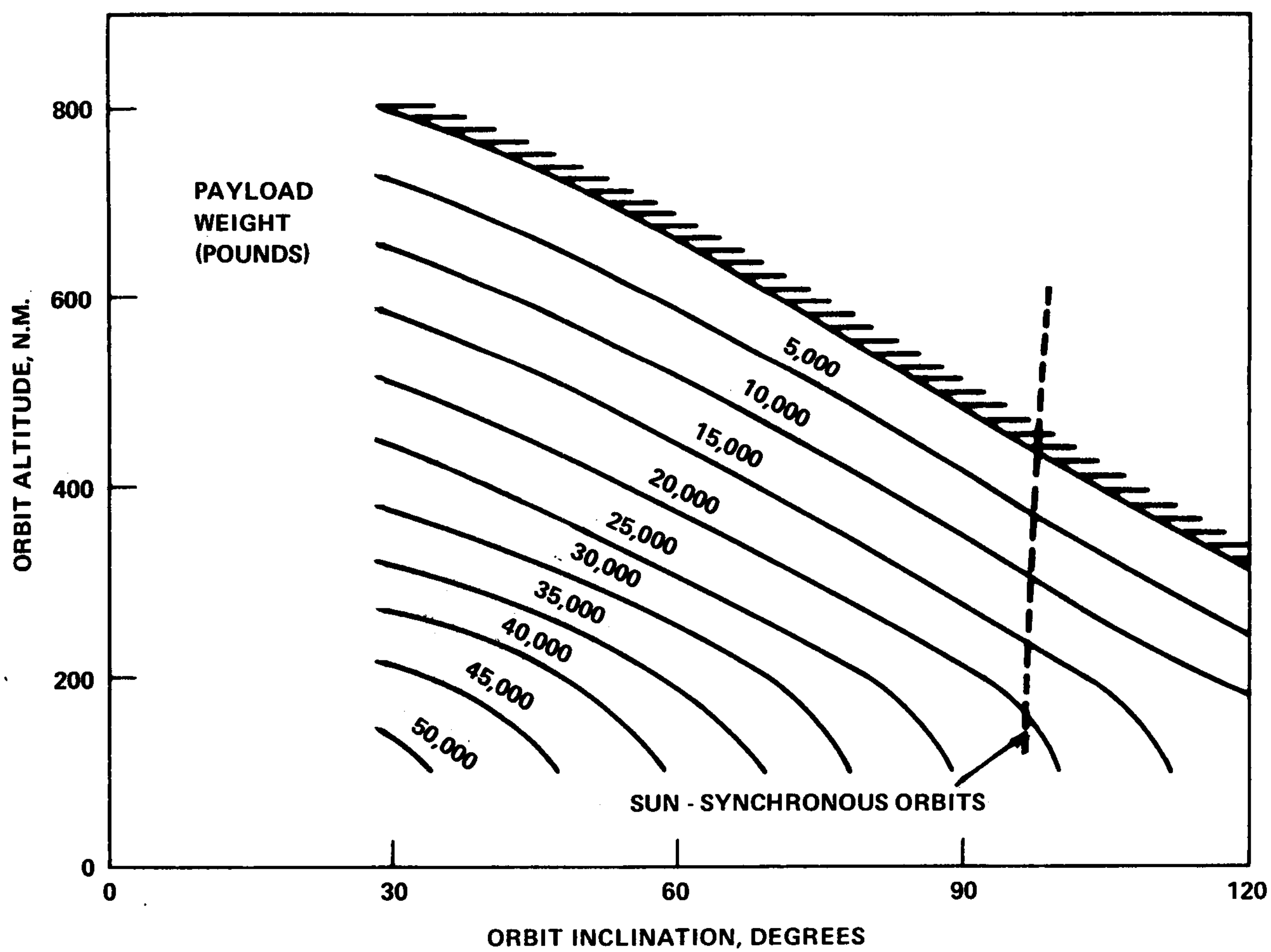

FIGURE 2 - ESTIMATED PAYLOAD DELIVERY CAPABILITY OF A 25K SHUTTLE (FROM REFERENCE 3)

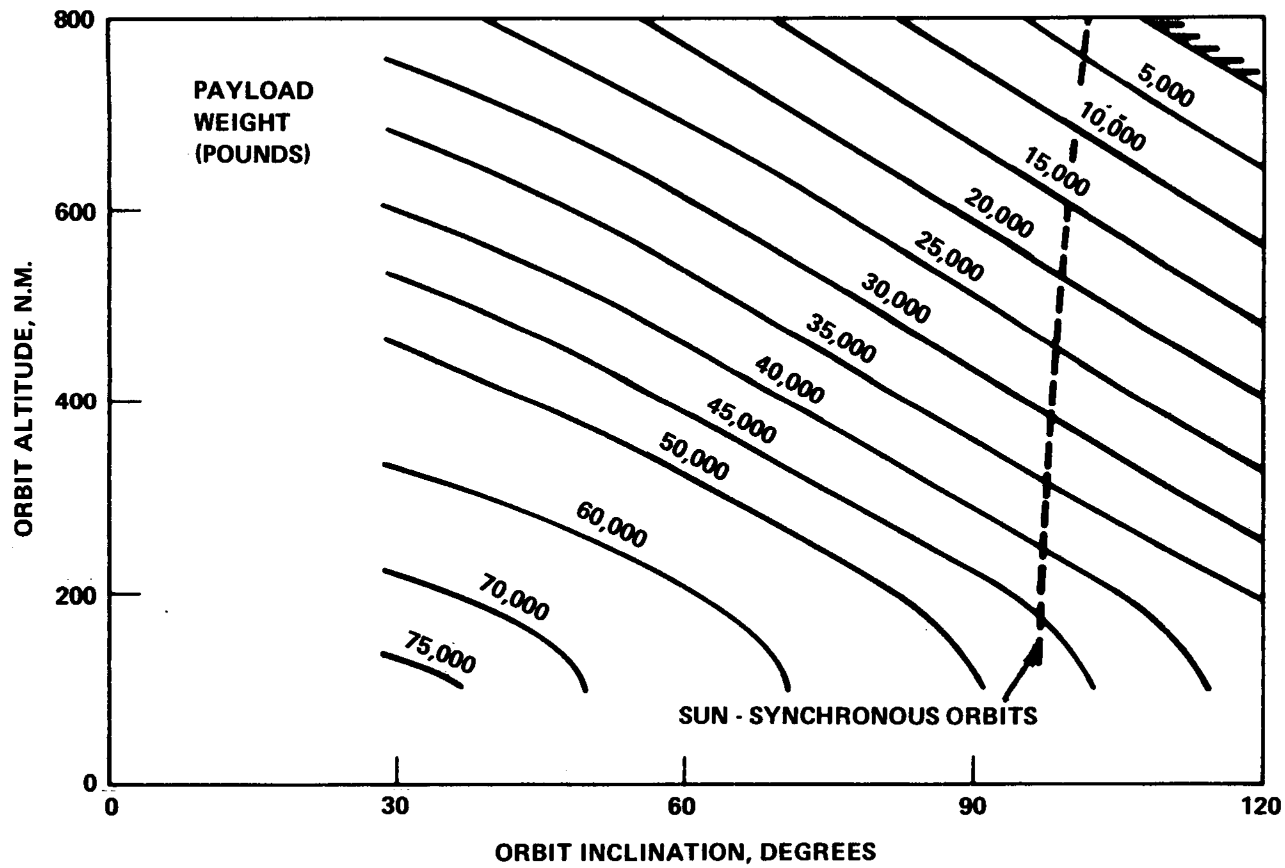

FIGURE 3 - ESTIMATED PAYLOAD DELIVERY CAPABILITY OF A 50K SHUTTLE (FROM REFERENCE 3)

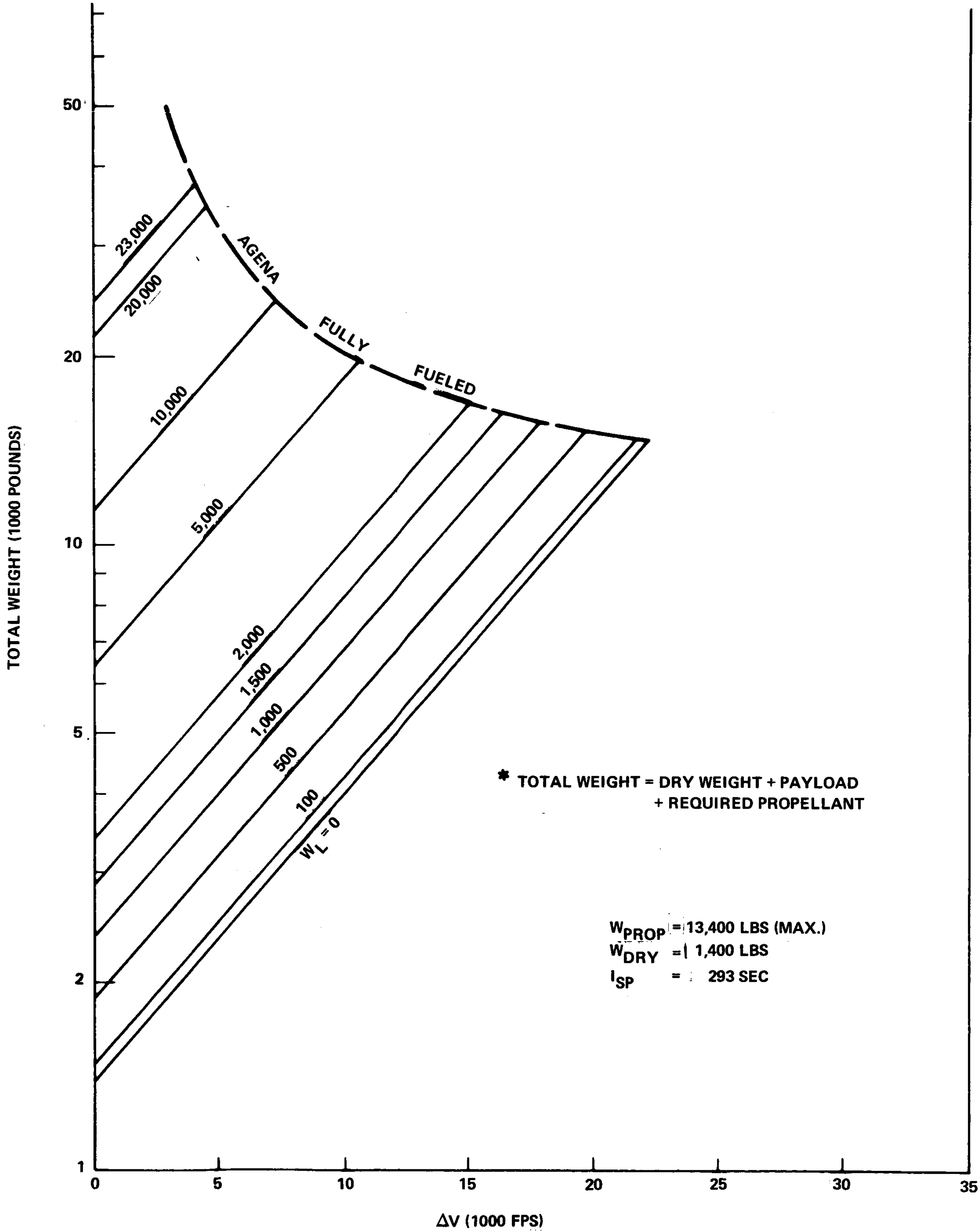

FIGURE 4 - AGENA TOTAL WEIGHT (W_T)* AS A FUNCTION OF PAYLOAD (W_L) AND VELOCITY INCREMENT (ΔV)

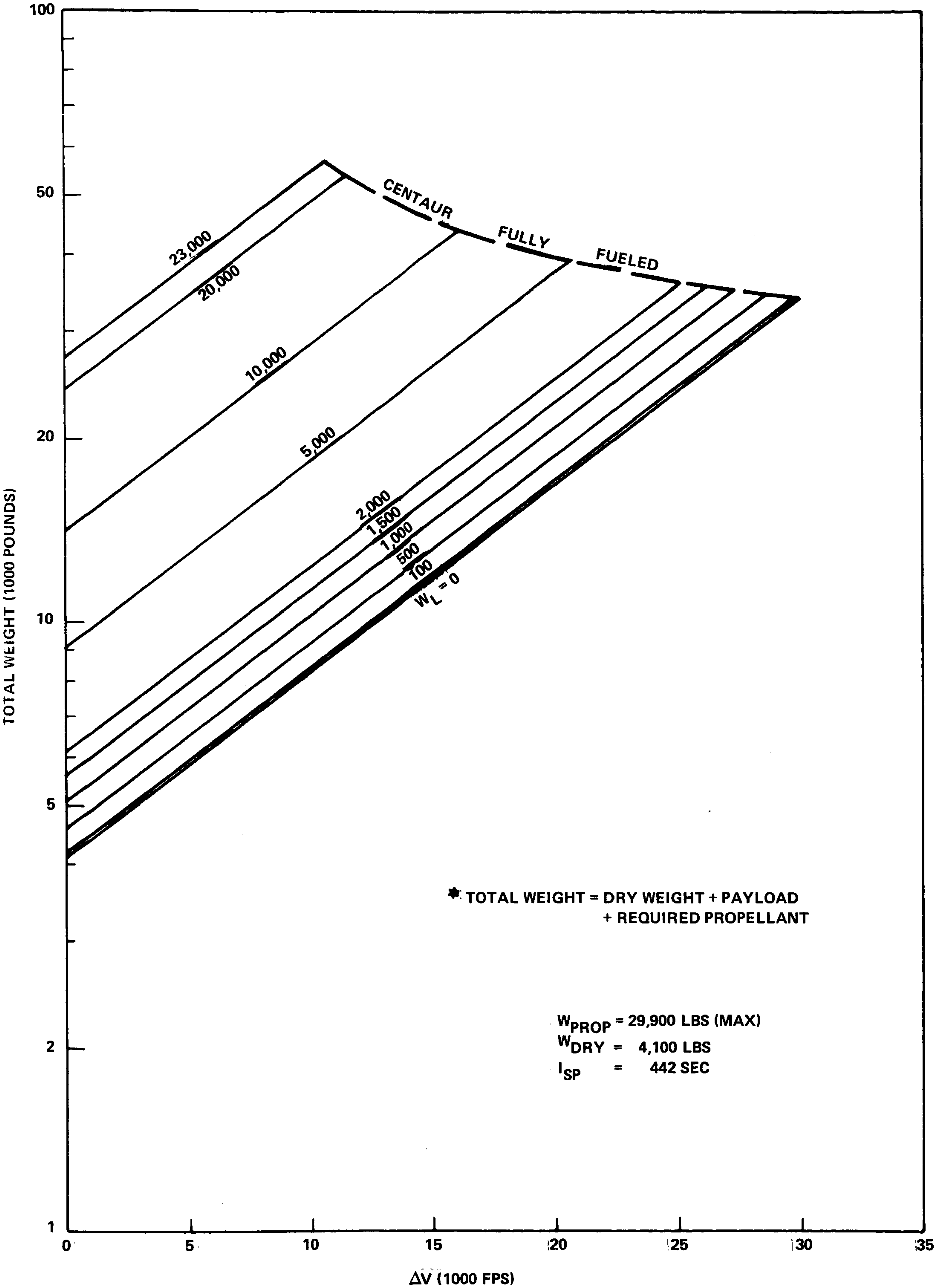

FIGURE 5 - CENTAUR TOTAL WEIGHT (W_T)* AS A FUNCTION OF PAYLOAD (W_L) AND VELOCITY INCREMENT (ΔV)

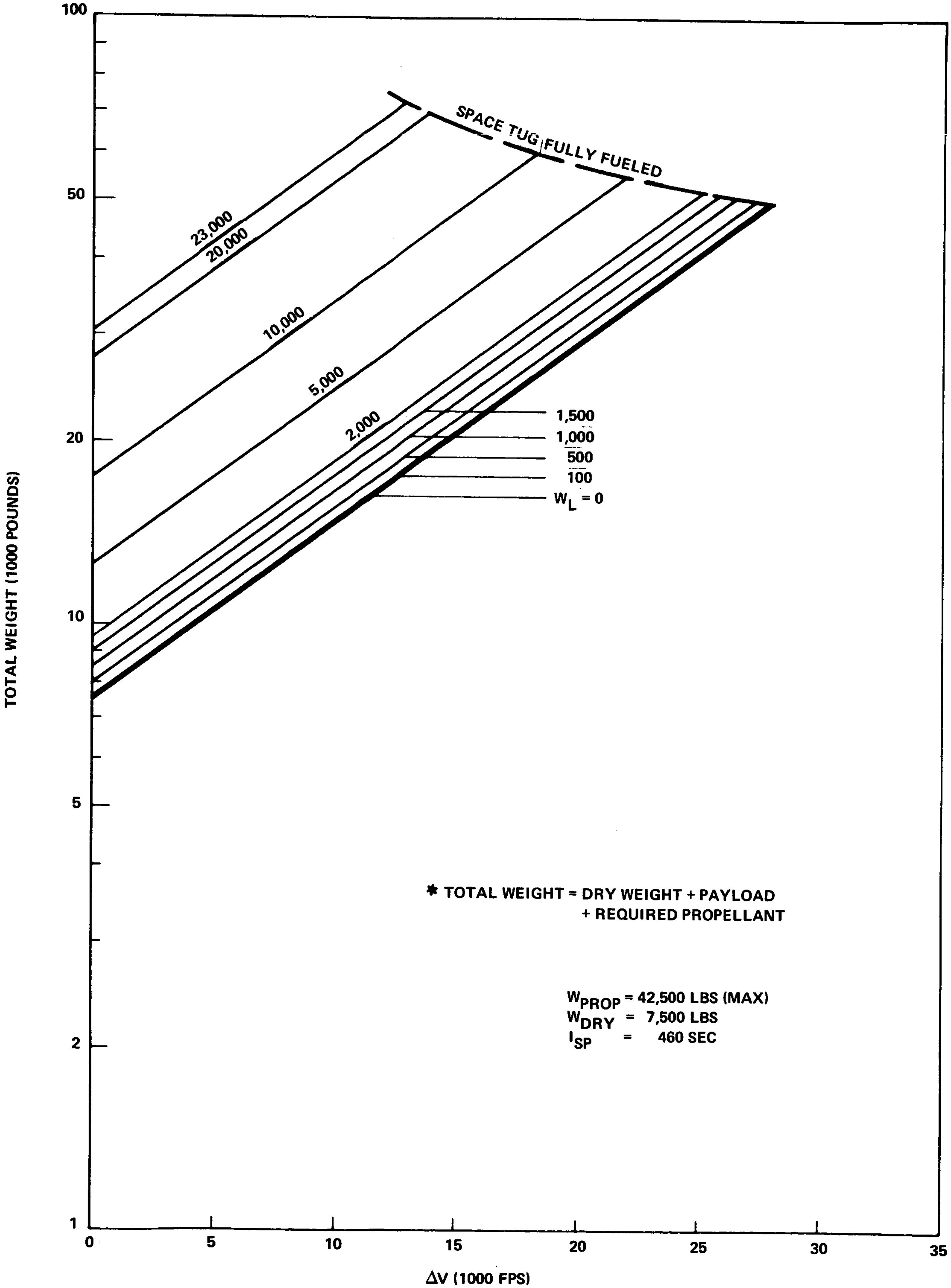

FIGURE 6 - TOTAL WEIGHT (W_T)* OF NONRECOVERABLE SPACE TUG AS A FUNCTION OF PAYLOAD (W_L) AND VELOCITY INCREMENT (ΔV)

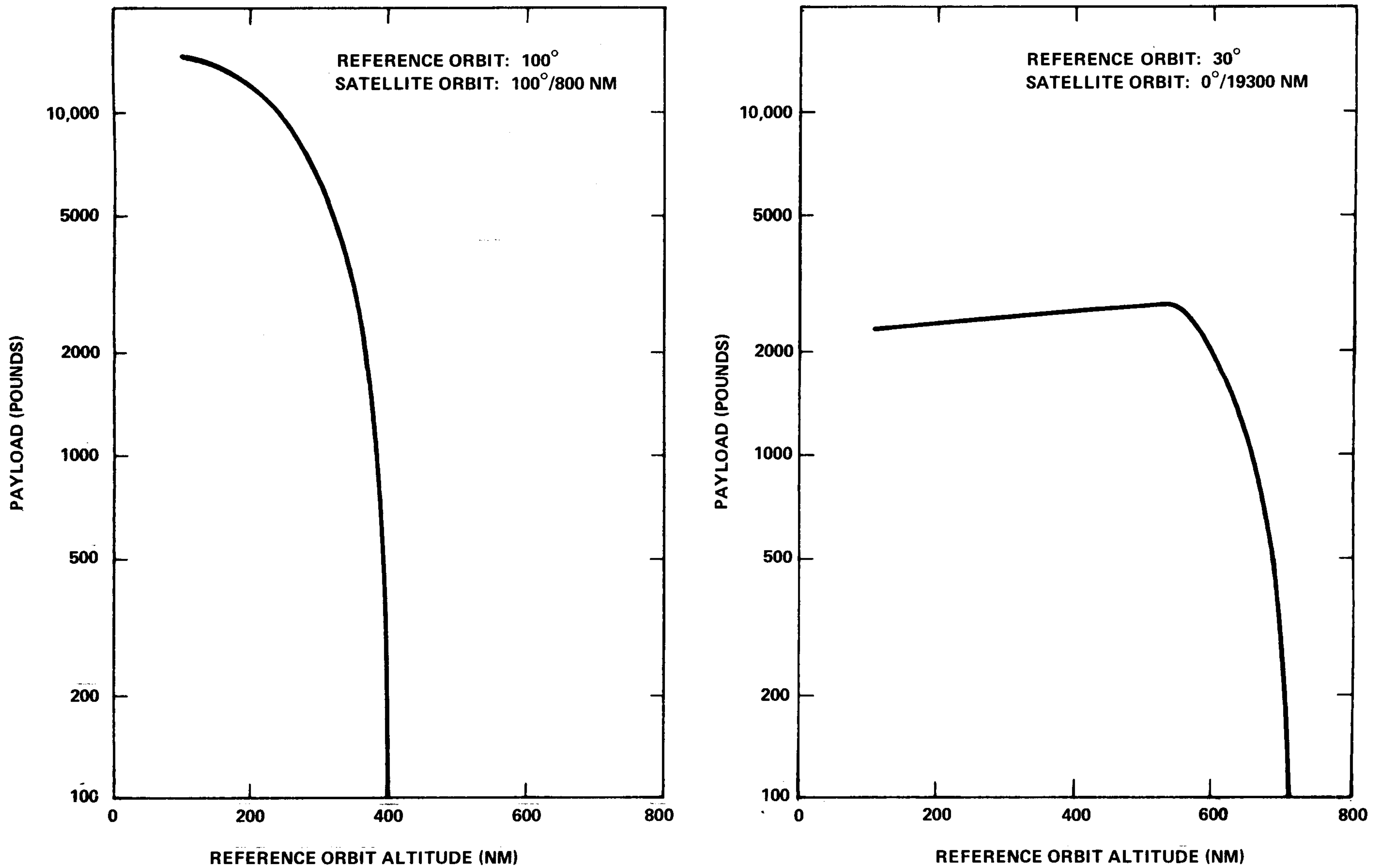

FIGURE 7 - MAXIMUM PAYLOAD DELIVERABLE TO TWO TYPICAL SATELLITE ORBITS WITH A 25K SHUTTLE/AGENA COMBINATION

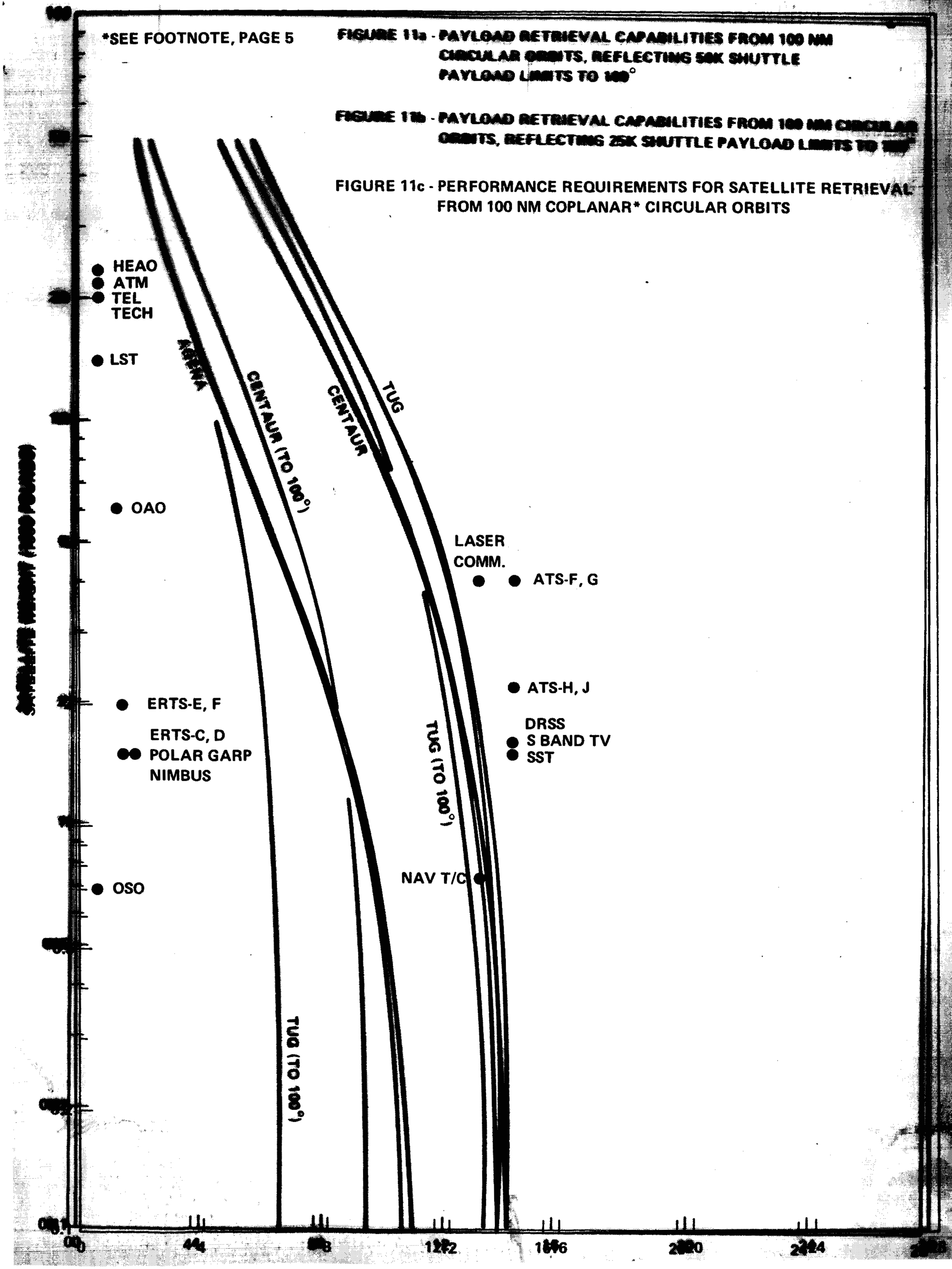

FIGURE 11a - PAYLOAD RETRIEVAL CAPABILITIES FROM 100 NM CIRCULAR ORBITS, REFLECTING 50K SHUTTLE PAYLOAD LIMITS TO 100°

FIGURE 11b - PAYLOAD RETRIEVAL CAPABILITIES FROM 100 NM CIRCULAR ORBITS, REFLECTING 25K SHUTTLE PAYLOAD LIMITS TO 100°

FIGURE 11c - PERFORMANCE REQUIREMENTS FOR SATELLITE RETRIEVAL FROM 100 NM COPLANAR* CIRCULAR ORBITS

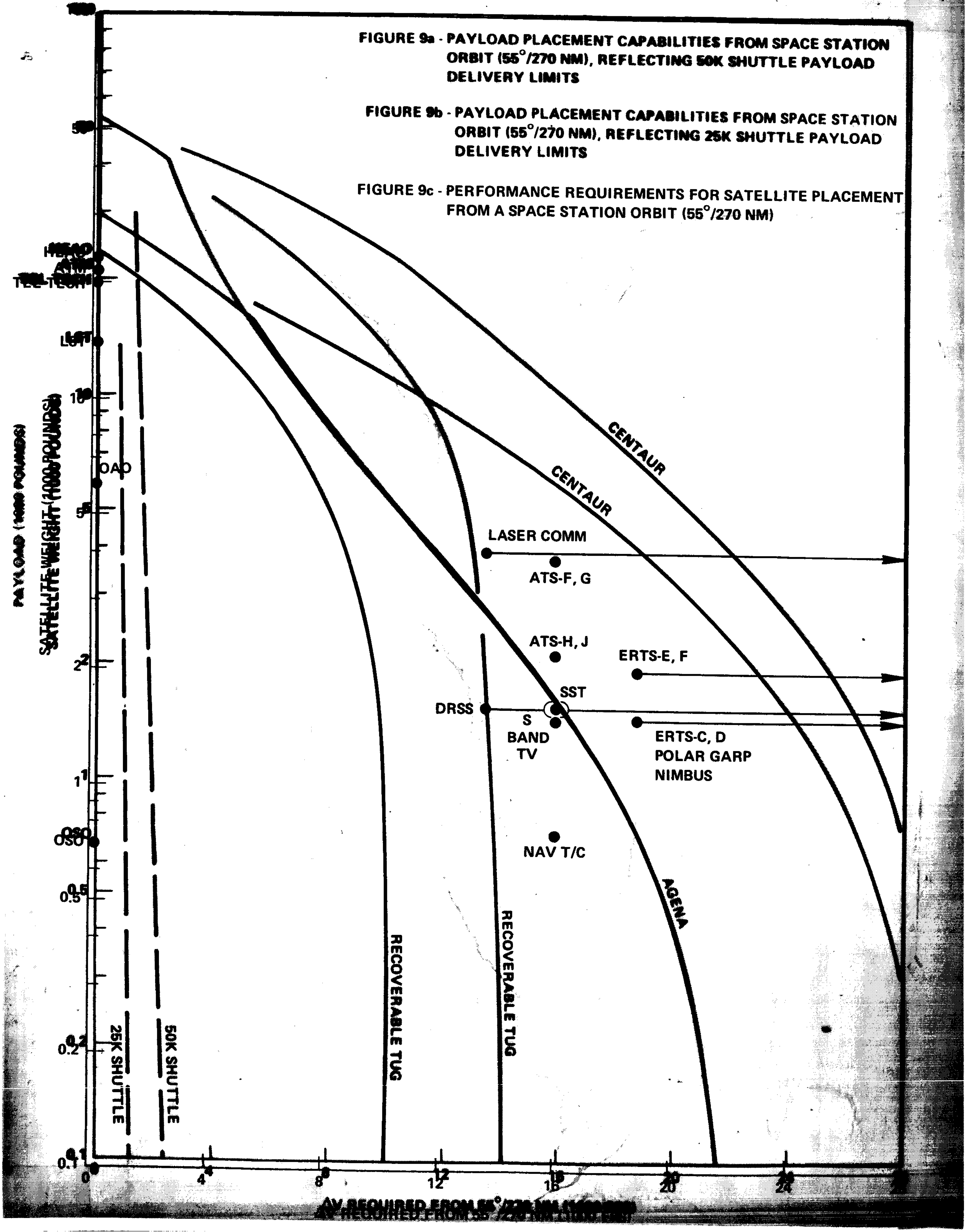

FIGURE 9a - PAYLOAD PLACEMENT CAPABILITIES FROM SPACE STATION ORBIT (55°/270 NM), REFLECTING 50K SHUTTLE PAYLOAD DELIVERY LIMITS

FIGURE 9b - PAYLOAD PLACEMENT CAPABILITIES FROM SPACE STATION ORBIT (55°/270 NM), REFLECTING 25K SHUTTLE PAYLOAD DELIVERY LIMITS

FIGURE 9c - PERFORMANCE REQUIREMENTS FOR SATELLITE PLACEMENT FROM A SPACE STATION ORBIT (55°/270 NM)

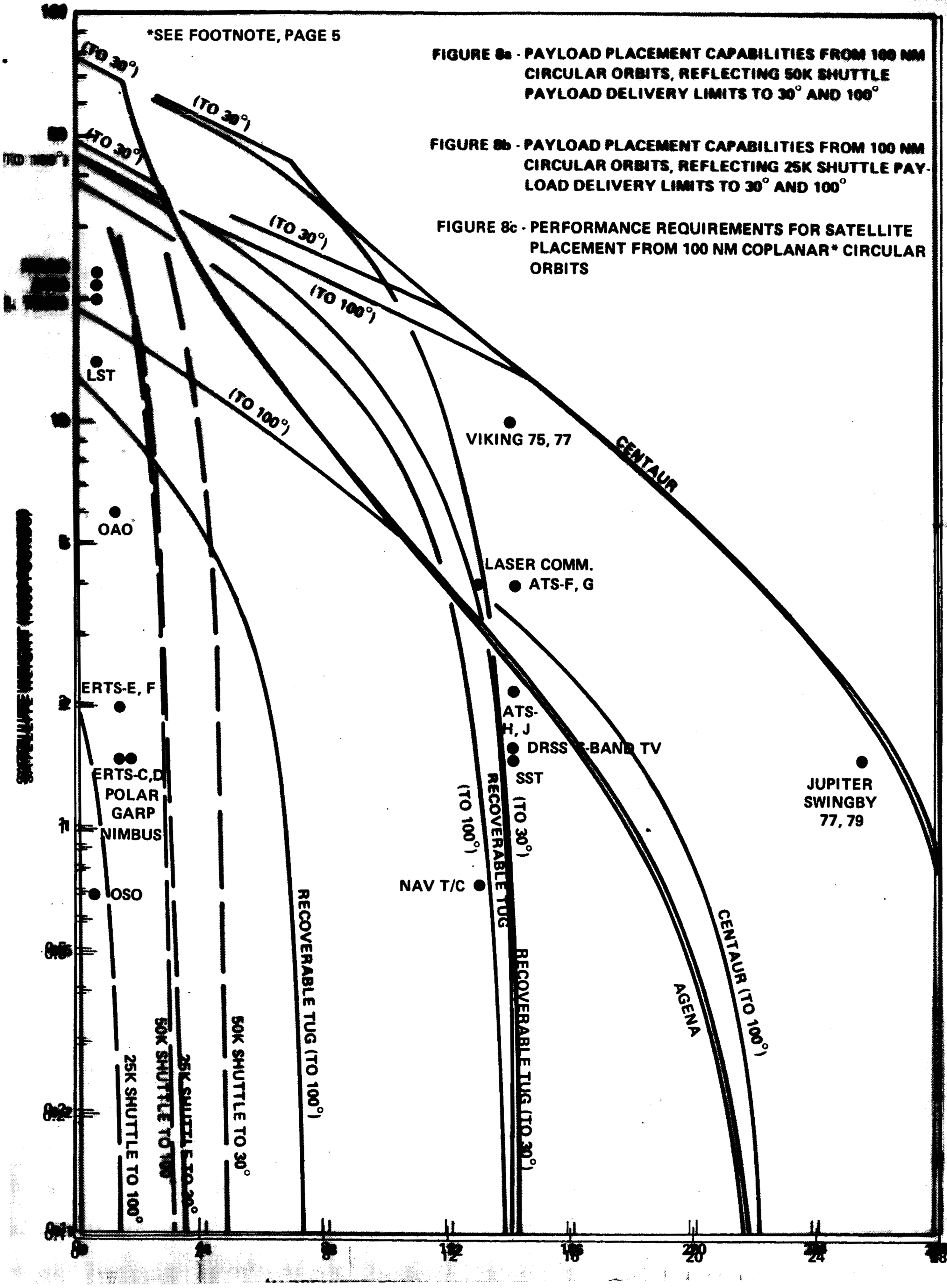

FIGURE 8a - PAYLOAD PLACEMENT CAPABILITIES FROM 100 NM CIRCULAR ORBITS, REFLECTING 50K SHUTTLE PAYLOAD DELIVERY LIMITS TO 30° AND 100°

FIGURE 8b - PAYLOAD PLACEMENT CAPABILITIES FROM 100 NM CIRCULAR ORBITS, REFLECTING 25K SHUTTLE PAYLOAD DELIVERY LIMITS TO 30° AND 100°

FIGURE 8c - PERFORMANCE REQUIREMENTS FOR SATELLITE PLACEMENT FROM 100 NM COPLANAR* CIRCULAR ORBITS

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